We've changed our name! See page 7

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Human Systems IAC

GATEWAY

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Figure 1. One of our CyberSeat virtual reality setups used to train participants to navigate through a building. In this case, the virtual building (inset) has been made transparent.

Using Virtual Environments for Training of Spatial Navigation

Marc M. Sebrechts
and the CVRL Team

Cognition & virtual reality laboratory
Department of Psychology
The Catholic University of America

Spatial navigation is important not only in our daily routine, but in a wide variety of complex critical tasks. For example, military forces, law enforcement personnel, and fire-fighters all encounter situations in which they must navigate through unfamiliar buildings to free hostages, disarm defenses, or locate people in need of rescue. In these circumstances, exploring the actual buildings is impractical or impossible, so another approach to spatial learning is needed that will support transfer to performance on the actual tasks. Virtual reality technology promises one potential solution to this need, and our research is designed to evaluate that approach. We are interested both in how well virtual environments (VE) mimic the real world and in how the VE can be transformed to improve on real-world training.

In navigating a space, it is generally acknowledged that there are two primary types of knowledge—route and survey. Specific paths constitute a "route" and enable a person to navigate from one location to another. Such routes are fairly specific and can be thought of as particular procedures. When a more global, integrated representation is developed, the person is said to possess "survey" knowledge of the space. Such knowledge enables a

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inside:

The Human Systems IAC is a United States Department of Defense Information Analysis Center administered by the Defense Technical Information Center, Ft. Belvoir, VA, technically managed by the Air Force Research Laboratory Human Effectiveness Directorate, Wright-Patterson Air Force Base, OH, and operated by Booz·Allen & Hamilton, Falls Church, VA.

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Figure 2. An exterior view of the virtual model of the Crough building of the School of Architecture and Planning used in our transfer studies. The inset shows the actual building.

person to navigate using a number of different paths. Although there is no consensus on the precise nature of the underlying representations, it is generally recognized that these two types of knowledge provide for rather different navigational skills.

The Cognition and Virtual Reality Laboratory at The Catholic University of America has focused on examining the role of VE in developing these two types of knowledge. This paper addresses three relevant questions within that framework—

1. Do VEs provide an effective way to learn a route?
2. Can VE improve the acquisition of survey knowledge for wayfinding and object localization?
3. Can VE change the character or speed of survey learning?

Of course, answers to these questions will depend both on what is presented to the user and on the interface tools controlling that presentation. Our emphasis has been on VE that can be set up in a space comparable to a normal work

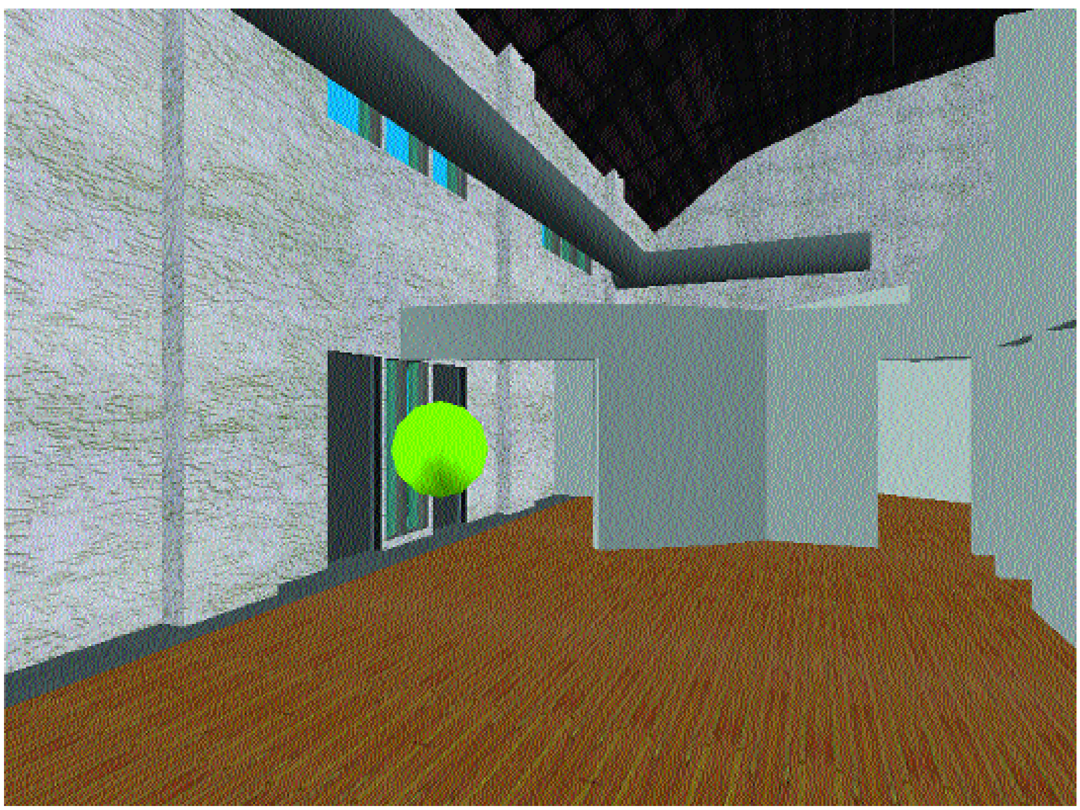

Figure 3. An interior scene of the virtual Crough building used in our exploratory VE studies. The sphere serves to enhance exploration of the building. It turns from red to green once that space has been explored.

area using mid-range, commercially available hardware and software (see Figure 1, page 1, for a typical setup).

Do VEs Provide an Effective Way to Learn a Route?

In a series of studies, we examined how walk-throughs in a VE transferred to following the same route in the actual building. Walkthroughs along a defined route in VE (see Figures 2 and 3) were compared with tracing the same path on a floor plan or walking the route in the actual building. When asked to follow the learned route in the real building on a transfer task, those trained in VE performed comparably to those trained in the actual building. However, when the transfer route in the real building was reversed, the VE trained group had substantially more difficulty than either of the other two conditions. This pattern of results was similar when people were tested immediately after learning or after a two-week delay. So, for purposes of route-following, VE can be a very good training method. However, VE also shows substantially more specificity than other traditional training methods—reversing a route is more difficult after VE training than after map or real-world training. One explanation for this specificity may be the restricted field of view. We tested this hypothesis by having participants learn in the real building using goggles that limited field of view to that used in our head-mounted display. The results suggested that the field of view only accounts for a portion of VE route learning specificity.

Can VE Improve the Acquisition of Survey Knowledge for Wayfinding and Object Localization?

Although learning to follow a specific route in a VE led to successful transfer, it did not generalize well to other routes. Is this specificity of learning a property of VE, or is it a function of a route learning task? To answer this question, we examined a different form of VE learning in which people explore the same large building space on their own, thus increasing their exposure to a variety of viewpoints.

When instructed to "explore" the virtual building until they were familiar with its spatial layout, people learned only parts of the space, apparently unaware of the limits of their exploration. We therefore enhanced the virtual space with a series of red spheres located at critical points in the building, and instructed people to locate all of the spheres. When they encountered a sphere, audio feedback indicated the current location, and the sphere turned green to indicate that the location had been visited (see Figure 3). This enhanced cueing improved exploration by providing a mechanism for exploration feedback not available in a physical space.

Transfer effectiveness was assessed using a wayfinding task that required people to go from one location to another using the most efficient path. On this task, training using a VE was far more efficient than training using a matched floor plan of the building. On average, VE paths were about 18% longer than optimal, whereas map paths were 68% longer.

These results are among the first demonstrations that virtual training can result in better wayfinding than map-based training. Presumably, exploratory

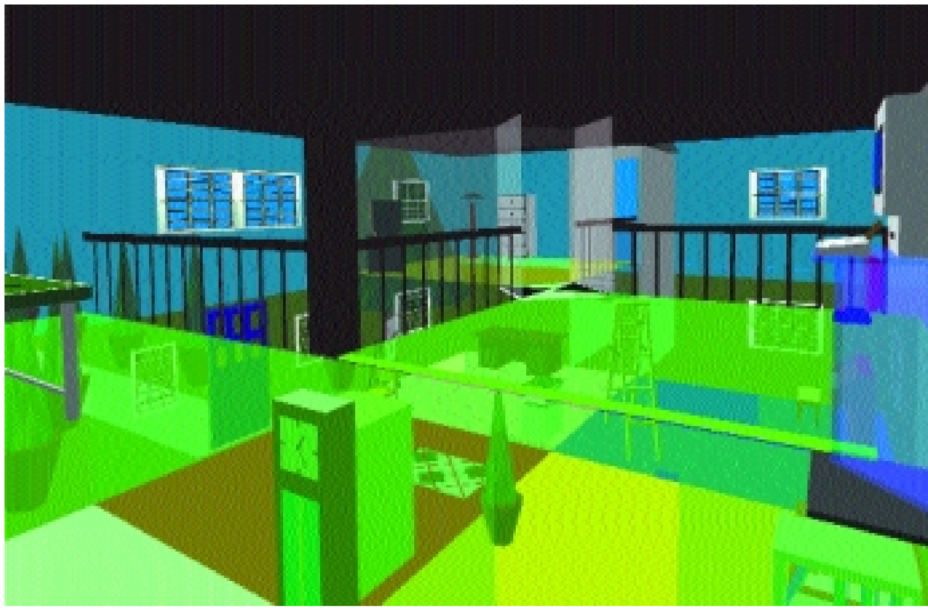

Figure 4. A screen-shot of the virtual Community Center as seen in the transparent condition which enabled people to see through floors and walls.

VE learning provides greater exposure to viewpoints that enhance the degree of survey knowledge.

In these same studies we examined how well people would do in identifying the location of objects they had found in the building. Would the VE serve as a better tool for precise object location? In a cued-recall task, people were shown photographs of objects they had seen in the building. They were asked to identify the objects' location in the actual building using either a map or a VE of the building. Those people who had learned the space in a VE and identified object location in the VE performed markedly better (57% of object placed within 5 feet of the correct location) than those who had either learned spatial lay-

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out or recalled object location using a map (28% within 5 feet).

Presumably, the detailed aspects of the display improved the precision of object placement. The same specificity that is a detriment in route following may be an asset in learning and retaining specific information about object location.

Can Altered VE Change the Character or Speed of Survey Learning?

Although most studies of VE training emphasize the mimicry of reality, VR technology also makes possible changes from reality that are not otherwise possible in real-world training. One of the problems posed by learning a specific route is that people often have difficulty with spatial relationships that are not along that route—they lack survey knowledge. What if people could see relationships that were not constrained by the route sequence by making structures transparent, the "X-ray vision" effect? In our laboratory we evaluated this approach by comparing VE training using a transparent-walled building (see Figure 4, page 3) with that using a typical opaque-walled building. We then assessed survey knowledge using both drawings and a speeded response-time task indicating relative location of objects in the building.

VR training in the transparent-walled building led to substantially more accurate floor-plan drawings than VR training in the traditional opaque-walled building. This advantage was mainly due to a more adequate understanding of the architectural aspects of the building's layout (e.g., connection of rooms and alignment of floors). Mental models developed from VR training reflect properties of the simulated environment. Learning a route in an opaque building led to a mental model that maintains route distance—identifying the relative location of objects in such a building depends upon the distance along the followed route, or what is known as a city-block metric. In contrast, learning a route in a transparent building led to a mental model with both route distance, reflecting the path that was followed during learning, and Euclidean distance or the straight line distance between objects that could be seen through walls. These results suggest that survey knowledge, which typically requires substantial time to learn in the physical world, may be acquired more quickly using VE models. In addition, transparency may provide a useful technique in the development of situation awareness.

Practical Implications

These results suggest a number of positive benefits for VE training as well as some limitations. VE can be useful for planning or mission rehearsal that involve spatial navigation. VE route-following results in successful transfer to the same task in a comparable physical space, and this can be extremely useful in preparing to move efficiently to a given location. At the same time, this type of virtual route following resulted in substantial specificity, limiting its use for selecting alternative routes. Allowing exploration in the VE induces more flexibility of learning. Building cues into the VE ensures that the potential space of interest is actually explored.

The relatively detailed visual layout of a VE may also provide improved reconnaissance. When a space was learned using VE and object location was recalled using that VE, accuracy of object placement improved dramatically. It is an open question whether this recall will generalize from specific scenes in the building to general descriptions of objects.

Finally, altering virtual environments offers special opportunities for modifying learning. Using transparent environments led to the acquisition of survey knowledge in a fraction of the time typically reported for real-world training. We have only begun to tap the links of virtual and real spatial navigation.■

Author's Note: The Cognition and Virtual Reality Laboratory research team includes Deborah M. Clawson, Ph.D., Benjamin A. Knott, Ph.D. (now at Booz·Allen & Hamilton), Michael Miller, M.A., Laura Mullin, B.A., and Michael Piller, B.S. The work reported here was supported by the Army Research Institute, contract DASW01–96–0004 and by the Office of Naval Research, contract N00014–97–1–0358. The content of this article does not necessarily reflect the position or policy of these organizations or of the U.S. Government.

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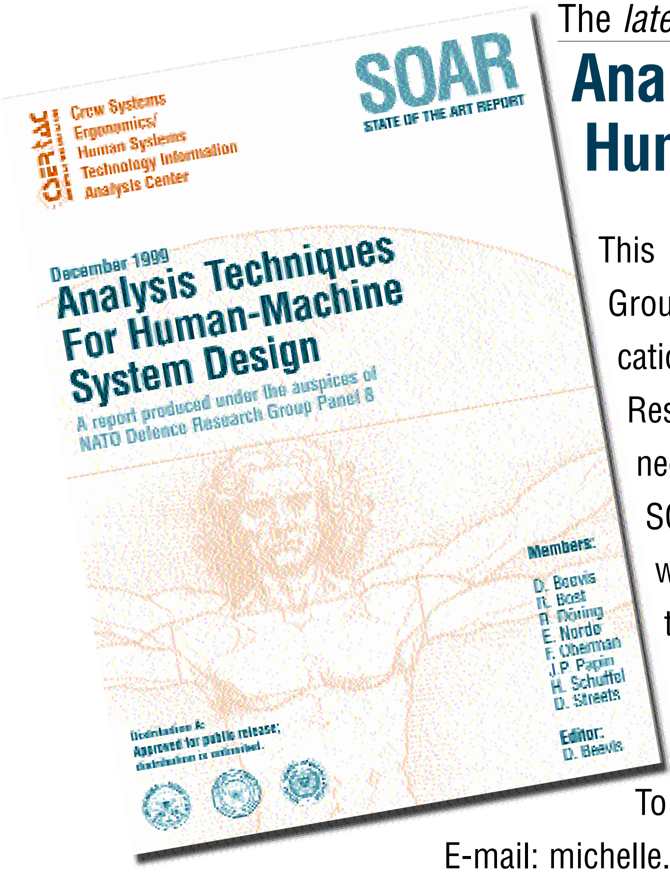

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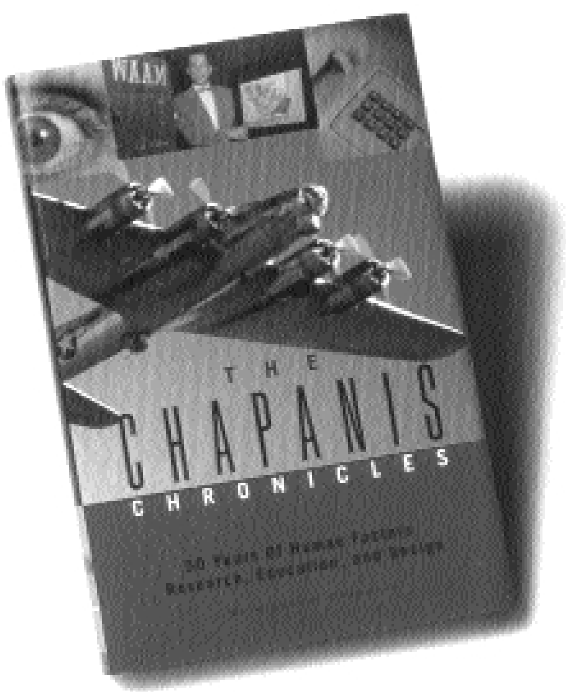

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Virtual Reality: A Special Issue of *Gateway*

guest column by
Benjamin Knott

Editor's Note: Benjamin A. Knott, Ph.D., an Associate at Booz·Allen & Hamilton, is serving as Guest Technical Editor for this issue of Gateway.

This issue of *Gateway* is the first in a series of special issues, each of which will focus on a single theme. The objective is to provide a brief overview of efforts within a field that is of interest to the human factors community. This issue is dedicated to the burgeoning field of Virtual Reality (VR). VR is a method of human-computer interaction, wherein a number of advanced interface technologies are employed to present the user with the illusion of being immersed in a computer-generated, or virtual, environment. This method has wide implications for training, medicine, data visualization, design, education, and entertainment, or any area in which having the capability to simulate a real environment can be of benefit.

While the idea of simulation is not new, the notion of "immersion" in a computer-generated space has gained considerable momentum over the last decade, spurred on by the emergence of a host of technological innovations. As the term "immersion" suggests, these innovations support a close coupling of human and machine. The users do not simply issue a sequence of commands to a computer, but rather they feel that they are a part of the virtual world. However, to fully realize the potential of this approach, a great deal of human factors research is needed to determine the most effective and safe manner in which to implement VR.

There are so many varieties of VR systems that it is difficult to define what exactly constitutes VR. These systems vary widely in their sophistication, from fully enclosed flight simulators that include detailed models of specific aircraft, to desktop implementations, sometimes called "Fishtank VR," where users peer into a virtual world through a standard computer monitor. While there is no prototypical VR system, most VR systems share three basic components—a computing environment, and immersive input and output devices. The computing environment consists of a virtual world database, software for rendering that database dynamically and in 3-D, and software for managing input from the user.

Many VR systems use multiple output devices to stimulate several of the users' sensory modalities. Visual displays usually take the form of a head-mounted display (HMD) or large image projection screens. Stereo images can be used to enhance the feeling of presence in the virtual environment. In addition, spatial audio, acoustic signals that sound like they are coming from a specific location in the virtual world, can be presented through headphones or speakers. Tactile, force feedback, and inertial displays stimulate a person's sense of touch and motion. While they are less common, they can be an important part of some VR applications. Examples of these devices include gloves that apply pressure or vibration to the skin when a virtual object is touched, or motion platforms that tilt and roll to give the user a feeling of flight.

Input devices usually include some way to control navigation and position tracking. Methods of navigation control vary considerably. The most common is a joystick or a mouse that allows movement in three dimensions. Others include treadmills or similar devices that allow one to use more natural body movements to move about (e.g., see article entitled "Virtual Environment Technology for Training," page 8, in this issue of *Gateway*). Position tracking devices sense the user's location and orientation with respect to the virtual world to update the appropriate displays (visual, auditory, or tactile). They are typically placed on the HMD to track the orientation and position of a user's head, allowing one to view the environment from any number of perspectives. Tracking of the hand will enable a person to grasp and move objects in the virtual world.

The technologies mentioned here are only a few of the possibilities. There are a variety of different types of HMDs, gloves, and tracking devices, each with unique properties and performance characteristics. In addition, new devices continue to be developed throughout a number of research and development laboratories. In fact, the sheer variety of devices and the ways in which they can be configured pose a substantial challenge to human factors professionals. To date, there are few standards or guides for VR design, and few sources from which to gather information on all the relevant techniques. When designing a virtual environment, for a training application, the designer must know about the alternative technologies that exist, how they are likely to affect learning and transfer, and how to produce the needed effect within a given budget. There is a growing literature on the human factors of VR, but the problem of gathering and synthesizing the research into useful guidelines for development is considerable. Perhaps what is needed is a single resource for information regarding VR research, tools, and techniques.

What follows is a series of articles that will explore some of the current research issues and describe promising user-centered applications of VR. The success of VR applications of the future, whether they are for training or entertainment, depends on careful consideration and research into the impact of the various technologies on human perception and learning. This issue offers a glimpse into that future.■

Why We Changed Our Name to
Human Systems IAC

On May 4, 2000 we officially changed our name from "Crew System Ergonomics/Human Systems Technology Information Analysis Center (CSERIAC)" to the "Human Systems Information Analysis Center (Human Systems IAC)."

The reason for the change is simple. The Human Systems IAC deals with the human component of a system using a "Total System Approach" in accordance with Department of Defense (DoD) policy to stress the importance of optimizing total system performance and minimizing the life-cycle cost of ownership. The total system includes not just the prime mission equipment, but also the people who operate, maintain, and support the system; the training and training devices; and the operational and support infrastructure.

The Human Systems IAC mission is now chartered by Director of Defense Research and Engineering (DDR&E) to collect, analyze, synthesize, generate, and disseminate scientific and technical data regarding the human in sea, land, air, and space environments.

Technical areas of interest include, but are not limited to general human factors engineering, ergonomics, MPT (manpower, personnel, and training), personnel survivability factors, health hazards, safety factors, medical factors, human characteristics, performance-related factors, human computer interactions, design of workstations and facilities, system characteristics, work design, standards, guidelines, codes of practice, and organization, social, economic and political aspects of ergonomics, methodology for research, test and evaluation, and other corresponding initiatives.

Virtual Environment Technology for Training

Nika Matzke and
Dylan Schmorrow

Virtual Environments (VEs) present realistic simulations of interactive scenes. The Office of Naval Research (ONR) has ongoing efforts aimed at developing VE systems to provide readily available, low-cost, and portable devices to train personnel on a broad range of operational and other skills. The training activities will range from maintenance operations to situation awareness and decision strategies in a battlefield setting. VEs will provide opportunities to train in situations that are either too costly or impractical to execute with traditional types of training exercises. VEs will also enable trainers to measure performance more accurately and efficiently than can be done through traditional training regimens. Having such performance measures and additional training opportunities before going into live missions will have a significant impact in timesavings, accident prevention, and survivability. Among the products of the ONR VE program to date are VEs to train operators in submarine piloting, shiphandling, and remotely operated vehicle piloting.

VEs have great potential in military training applications, yet the current capabilities are limited. VE training systems are computationally challenging. They require complex modeling of human perception and cognition, and they are currently limited to a very restricted range of task domains. Future systems need more flexibility and should be generic enough that they can be reconfigured for application in a multitude of contexts. Another potential direction is networking multiple VE systems over distributed sites for interactive VE use. Distributed networks of VE systems will allow users to interact with one another, creating a convenient and powerful mode of relaying information and training personnel. There are several areas that the ONR VE program will investigate to improve current capabilities of VEs. One that is particularly relevant to human factors is perception.

Perceptual Issues in VEs

A very important and often overlooked aspect of the development and design of emerging technologies is human sensation and perception. The ubiquitous and loosely used term, “multimodal,” refers to the use of multiple sensory input in VE systems. Many systems that are deemed multimodal are at best bimodal (e.g., incorporating visual and haptic input). Fully immersive multimodal systems will contain several sensory-perceptual modes such as visual, auditory, haptic, kinesthetic, and proprioceptive input. Understanding how our sensory perception operates will, among other things, improve depth perception in VEs, facilitate production of apparent motion, and increase the accuracy of spatial relationships and distance judgments in VEs.

Future Directions

The ONR VE program has access to an excellent group of researchers who have helped us shape the future of the program. Below are some of the exciting new projects along with some ongoing projects that will be pursued in the years ahead.

Sensory Perceptual Issues Beyond High-Fidelity Graphics

Spatial audio, virtual sound, and the integration of virtual with real sound will be among the future components of VEs. Although sound likely adds to the fidelity of a VE, for the purposes of the ONR VE program, the value of auditory input in VEs will

Figure 1. LCDR Dylan Schmorrow in an immersive computer-generated 3-D environment developed by the Institute for Simulation and Training, University of Central Florida.

need to be examined. For example, researchers will need to examine whether sound in VEs enhances situation awareness, increases the accuracy of localizing objects, or aids in judging location relative to sound sources (i.e., to aid in navigation).

Initial studies investigating the use of sound in VEs for distance and location estimates of objects showed that localization of sound is very difficult unless the sound is stationary. In fact, humans are much more accurate using vision as opposed to sound for distance estimation. That finding may partially be due to limitations of human sensory capacity, but also due to current limitations of available sound devices. As technological advances and improvements in spatial audio occur, the value of auditory input in VEs is more likely to be seen.

"Haptic" refers to the sense of touch and force feedback information from the muscles and joints. Haptic devices will be used for various purposes including use as a navigational aid. For instance, pilots could receive haptic input for signaling their direction or location. Another potential application of haptic devices will be the manipulation and interaction with objects in VEs.

Including inputs that provide a sense of awareness of movements and position of the body (proprioception) that is independent of vision in VEs also enhances performance on certain tasks. In one study, researchers showed that self-propelled locomotion increases accuracy in localization of objects and judgments of position relative to stationary objects.

While self-locomotion is clearly a value-added navigational aid, not all VEs will have the space for the user to move about unconstrained. Thus methods to mimic kinesthesia (the illusion of moving in space) are likely to be further developed. For example, the Naval Research Laboratory is developing a locomotion interface called "Gaiter" that permits a natural walking-in-place interface for moving about in large-scale VEs. That particular system uses wireless tracking devices to monitor the user's movements walking or running in place, and moves the user's viewpoint through VE to give the user the impression of virtual movement. Even though the user knows he is walking in place, presenting optical flow scaled to correlate with the user's knee motion makes it possible for a user to suspend his disbelief and participate in the illusion of false motion.

Of course, a drawback to incorporating perceptual input in VEs is the potential adverse side effects from perceived and apparent motion. Current systems, including those that utilize head-mounted displays (HMD) (see Figure 1), may have negative effects on the user such as motion sickness and postural instability. Studies with HMDs have shown that factors contributing to adverse side effects include visual update delays, field of view, and resolution quality. Additional side effects can occur when VE systems are used on moving platforms such as ships. Therefore, efforts to circumvent or mitigate adverse effects are an important part of the ONR VE program.

Simulating Natural Actions for Close-quarters Battle

Simulating real-life environments requires providing input to and tracking output from the user. The input can include providing the user with a sense of a representation of his body (avatar). Having the user make contact with virtual objects can also help simulate natural interaction. The application platforms for future VE systems range from submersible vehicles to computer-generated ground forces (see example in Figure 2).

Modifiable VEs for Distributed Interaction

Basic and reconfigurable scenario development will be another future direction for VE systems. VEs should have the capability to be modified, as the users' training needs change. Additionally, the systems will eventually be networked so that instructors can reach a large number of trainees at distributed sites and so that the trainees can interact with one another. The major

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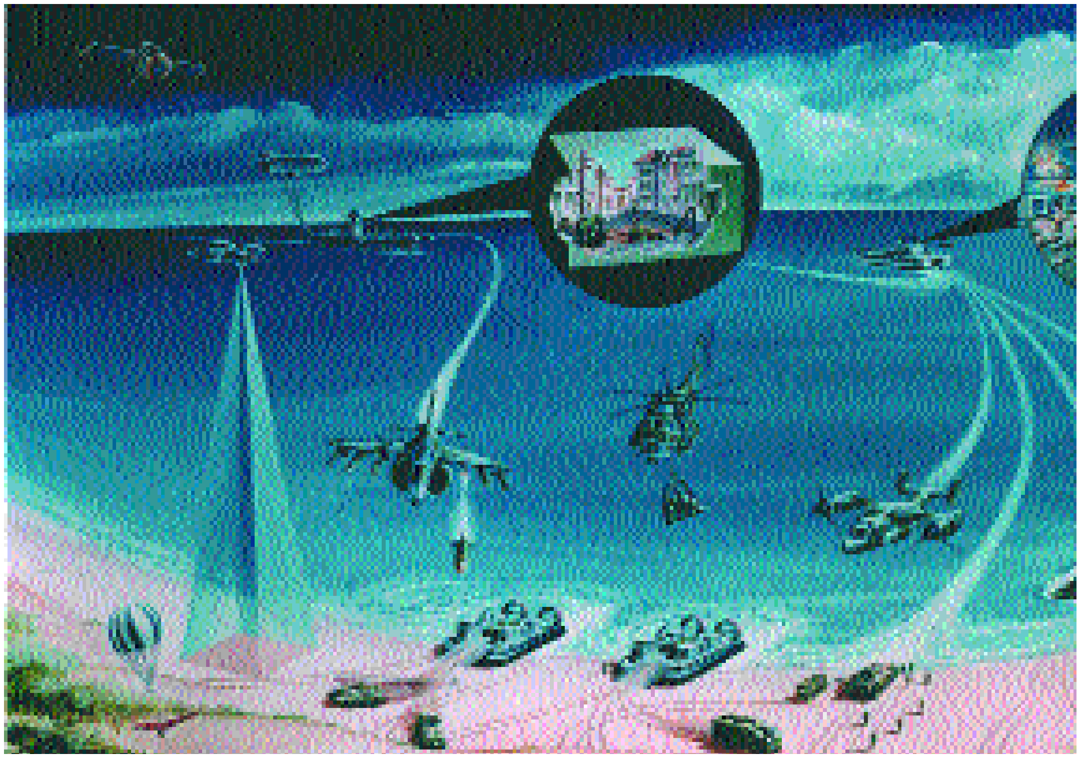

Figure 2. A visionary example of VE systems that will encompass blue-water simulations to computer-generated forces on the ground.

appeal of a distributed approach for the military is the ability to deploy the training device along with military personnel.

Tactical Navigation

A major use of VEs has been and will continue to be the training of spatial skills for navigation. Spatial abilities involve the acquisition and use of spatial knowledge used for wayfinding, search, map use, and direction and distance estimation. Haptic auditory, and kinesthetic or proprioceptive types of information as navigation aids are important areas to investigate for their usefulness in tactical navigation.

Instrumentation System for Analysis of Human Performance

A key component of training in VEs will be the ability to predict performance in the real world. Methods for tracking and analyzing the user's actions will likely be developed and included in VE systems. While training itself should produce improvement in performance measures, providing the user with feedback from analyses of the user's actions should also help improve performance.

Keeping Up With the ONR VE Program

VEs are exciting new tools to exploit for training and other purposes. Their success in training applications will likely depend upon the measurable transfer from the VE to real-world execution. Positive transfer may depend upon the fidelity of the VE itself. How "real" the VE must be to facilitate learning and retention will be one of the many questions the ONR VE program intends to answer.■

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Warfighter-centered Virtual Reality Technology

Michael W. Haas
Dee H. Andrews

The Human Effectiveness Directorate of the Air Force Research Laboratory (AFRL) initiated its research and exploratory development of warfighter-centered virtual reality technology in the 1940s, well before the term "virtual reality" was coined. Flight simulation provided the original need for virtual reality beginning with the "Link" trainer of the type used during World War II for teaching pilots proper procedures of instrument flight. For many years, flight simulation was the major impetus for virtual reality advances in areas such as visual systems, cueing, and the simulation of highly realistic aerodynamic modeling. As defined in 1992 by the National Research Council's Committee on Human Factors,

"Virtual Reality is the experience of being in a synthetic (simulated) environment and of perceiving and interacting through sensors and effectors, actively or passively, with it and the objects in it as if they were real."

The Human Effectiveness Directorate continues to lead technical innovation in the virtual reality technologies of aircrew training, flight simulation, and partially immersive warfighter interfaces.

Training and Flight Simulation

The Human Effectiveness Directorate of AFRL (and its predecessors) has had a major part to play in both advancing virtual reality for flight simulation technologies and in understanding how to best use those technologies to train warfighters. Current virtual reality technology areas that the Directorate is pursuing to improve flight simulation for training include visual systems, representation technology, and interconnection technology.

Visual systems technology can be divided into three interactive components. The database contains information about the terrain and man-made objects that are to be represented in the visual scene. The image generator takes the information from the database and allows its visual representation to be displayed to the trainee. The visual display itself is the third technology. The Directorate has significantly contributed vital improvements to all three technologies over the years. For example, the current display of choice throughout the world for portraying out-the-windscreen visuals is a virtual-real image display developed within the Directorate (see Figure 1). Also, the Directorate has worked closely with industrial partners to improve the database generation and image generation capability, as well as new forms of visual display. Due to this work, the long-held goal of providing eye-limiting resolution in simulator visual systems is within reach.

Figure 1. A pilot in the F–16C Multi-task Trainer flying in a high-resolution database in a virtual-real image display. The entire system was developed at HEA's Mesa, Arizona facility. The database depicts Nellis AFB, Nevada. The resolution of the virtual image around the air base is 0.5 meters. As the pilot flies to the Nellis Ranges, the resolution drops off to about 4–5 meters.

To provide realistic warfighter training it is vital that the virtual battlespace be populated with realistic entities, either via human-in-the-loop simulations or through computer-generated synthetic forces. The Directorate has worked closely with the computer-generated forces community to help provide valid and accurate models of warfigher cognition and behaviors. Realistic threat systems and virtual enemy and friendly aircrews allow trainees to hone their skills against intelligent forces that represent the actual battlespace.

The Directorate has also been an active contributor to the improvement and application of interconnection technology and protocols for linking virtual (human-in-loop simulators), live (aircraft on ranges), and constructive (computer-generated threats and forces) training assets. This interconnection technology has now made it possible for warfighters to link to training assets literally around the world so they can enter training scenarios with disparate forces on an on-demand basis. That means an aircrew can literally sit in an F–15C simulator cockpit at Eglin AFB, Florida and be connected to, for example, F–15C human-in-the-loop simulators at Langley AFB, Virginia, F–16C simulators at Shaw AFB, South Carolina, and AWACS real aircraft at Tinker AFB, Oklahoma. This ability to link to virtual, live, and constructive assets provides a powerful synthetic battlefield that can be accessed from anywhere in the world.

Interface Technology for the Warfighter

Beginning in the 1960s, miniature cathode ray tube components, lightweight head-mounted optics, high-voltage connectors, and position/attitude helmet-tracking systems were the initial technologies developed within the Human Effectiveness Directorate for integration into helmet-mounted displays and sights. Then, as well as now, a helmet display, when combined with an accurate head-tracking system, enables intuitive control of complex weapon systems and a spatially stabilized, partially immersive visual environment. As these technologies were matured and integrated into helmet system prototypes by the Human Effectiveness Directorate, performance and affordability improved leading to flight simulator evaluations, flight testing, and the establishment of a joint service Helmet-mounted System Acquisition Program Office. It is possible that in future aircraft, the stabilized displays of a helmet system may replace the heads-up display common to many current combat aircraft.

Increased weapon system performance gained by utilizing a partially immersive visual environment appears to be amplified when the visual environment is supplemented with auditory and haptic displays. The Human Effectiveness Directorate is continuing its pioneering development of displays which spatialize multiple audio signals in real time.

Figure 2. A multi-sensory partially immersive crew station concept produced under the U.S./French Super Cockpit Program is under evaluation in the Human Effectiveness Directorate's Synthesized Immersion Research Environment.

The Directorate is also innovatively combining head-mounted visual displays, spatial-audio displays, and haptic displays into prototype crew stations and evaluating them in research flight simulators for inhabited and uninhabited aircraft. This research and development have attracted international interest and led to collaborations with countries such as France, the United Kingdom, Australia, and Sweden (see Figure 2).

Most recently, researchers within the Human Effectiveness Directorate have established a paradigm shift in the design of interfaces incorporating partially immersive displays. The shift, simply put, is that the system with which an operator interacts needs to be capable of estimating the mental and physical state of the operator using physiologic and behavioral indices, and based upon that estimate, adapt its behavior to best support the operator. In essence, systems of the future will react to the perceptual, cognitive, and physical capabilities of the operator, perhaps even evolving over time. This novel direction in design is immature but holds great promise for increasing the effectiveness of humans interacting with complex systems which incorporate partially immersive displays operating in highly dynamic and time-critical military environments.■

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Simulator Sickness in Virtual Environments

Bob Witmer &
Donald Lampton

Figure 1. VE Interface for Team Training Research developed by ARI and the Institute for Simulation and Training.

The U.S. Army has invested heavily in the use of virtual environments (VE) for training. Beginning in the 1980s with networked simulators, the Army has committed to use virtual simulations to train combat forces and to evaluate new systems and operational concepts. These simulations have focused on training personnel who fight from within combat vehicles.

More recently, the need to train dismounted soldiers in these simulations has been recognized. Responding to this need, the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI), Simulator Systems Research Unit, initiated a research program in 1992 to investigate the use of VE technology to train dismounted soldiers. After analyzing dismounted soldier tasks and reviewing the VE training literature, we investigated interface effects on users' capability to perform simple visual and psychomotor tasks in VEs. We then examined VE effectiveness for teaching the configuration of and routes through large buildings, and the transfer of the knowledge acquired to the real world. These results led to basic research into the problems of distance estimation in VEs. We also used VE to represent exterior terrain, both for training land navigation skills, and transfer to the actual terrain.

Recently, we investigated the value of navigation aids for improving configuration knowledge acquisition in a VE. Currently we are examining using VE for training team tasks (see Figure 1). Overall, we have conducted 15 experiments involving 690 participants. Knerr et al. (1998) summarize this research.

In each experiment, we monitored participants for simulator sickness and measured their symptoms. Simulator sickness refers to symptoms resulting from performing a task in a simulator that do not occur when performing the task in the real world. Symptoms include nausea, dizziness, headache, and eyestrain and are measured by a 16-item Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993). Because VE exposure produces similar symptoms, we consider VE sickness a subcategory of simulator sickness. VE sickness produces discomfort that may distract the trainee, possibly interfering with learning and training transfer and reducing the sense of presence in the VE. Severe discomfort may discourage further user participation in the training. Aftereffects involving the sense of balance, such as postural disequilibrium (ataxia), or involving visual flashbacks could possibly impair the users' ability to drive safely or perform skilled motor tasks following VE exposure.

VE sickness symptoms have been sufficiently severe that 8.4% (58/690) of our participants have withdrawn from experiments. Attrition rates for individual experiments varied from 0% to 25%. The experiments with high attrition rates tended to involve frequent self-motion and periods of constant VE exposure (i.e., exceeding 10 minutes between breaks). Figure 2 shows that for experiments with substantial attrition rates, SSQ scores were much higher for participants who withdrew before completing the experiments. Some who withdrew exhibited symptoms within the first five minutes, although average time before withdrawing was typically longer. For example, the average VE exposure time before withdrawal was 28 minutes for participants exposed to a VE over several sessions interspersed with short breaks.

For those who persevere, the severity of symptoms seems to accumulate, at least up to a point, over time of immersion. When symptoms were measured before, midway through, after an average immersion of 30 minutes, and after a 30-minute recovery period, the midpoint SSQ scores were significantly higher than the pre-immersion scores, but the midpoint and post-immersion scores did not differ. During the 30-minute recovery period scores returned to pre-immersion levels. Another study produced a slightly different pattern over five VE immersions, with symptoms increasing significantly during the first immersion and falling back during the next immersion. VE sickness gradually increased over the remaining immersions to peak on the last immersion.

Predicting Individual Susceptibility

In some experiments, participants reported whether they had ever experienced motion sickness and rated their susceptibility. Correlations of these items with post-immersion SSQ scores were significant, but small (.18 and .16 respectively). Although it appears that motion sickness susceptibility is related to VE sickness, VE sickness often occurs in the absence of any significant motion. Recently we developed a 14-item screening questionnaire targeted at predicting VE sickness. While the validity of this questionnaire has not been established, preliminary results are encouraging, with significant correlations between the screening questionnaire and SSQ scores of .38 to .56.

Practices Adopted

In conducting our research, we have adopted practices to reduce simulator sickness among our participants. While these have not been validated formally, they are based on pilot testing and our own personal experience and reactions.

For the first VE exposure, we use short sessions (10–15 minutes) interspersed with breaks (5–10 minutes). If the participant is standing, we provide a stable surface for hand contact. Participants are instructed to avoid quick, jerky head and body movements. The room is kept cooler than normal, with fans providing air movement to decrease discomfort.

Conclusions

VE sickness can negatively affect the use of VE for training. Roughly 10% of the population may not be able to use today's immersive VEs. Initial exposures to VE should be short with frequent breaks, and recovery periods should be provided for those who report moderate to severe symptoms. While the reduction or elimination of VE sickness is a long-term goal, in the short term we need better tools for identifying those participants who are most susceptible to VE sickness.■

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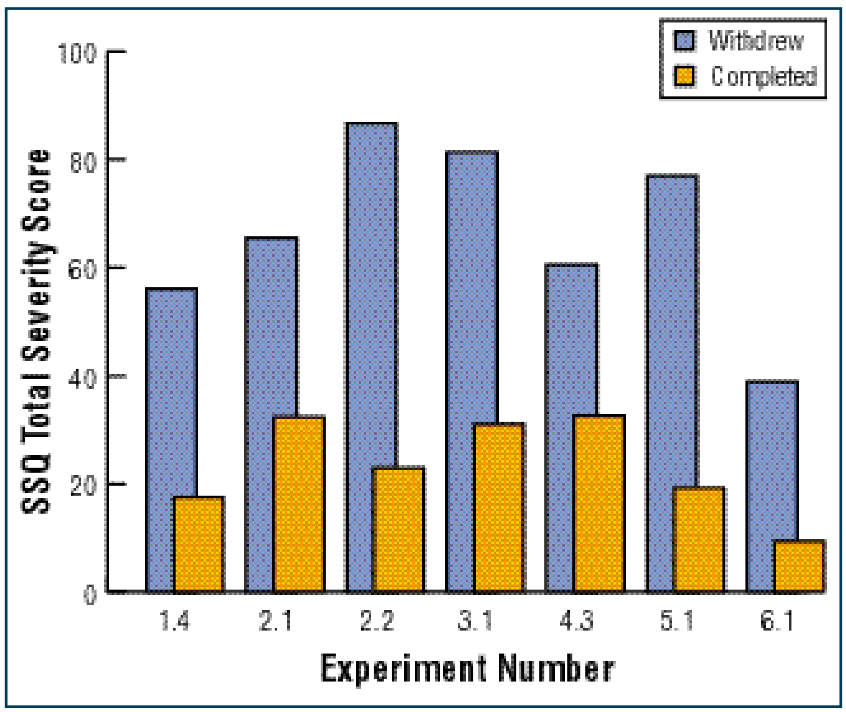

Figure 2. SSQ scores for users who completed or withdrew from experiments.

Potential Rehabilitation Benefits of Virtual Reality

Cheryl Trepagnier

Virtual Reality (VR) now plays a mainstream role in automotive design and pilot training. Gaming has brought VR displays into arcades and homes. Phobias are being treated through virtual exposure, with results comparable to those of standard treatment. Patients engaged in VR activities are finding relief from the pain of having burn wounds dressed. Physicians practice virtual laparoscopic surgery before moving on to the real thing, and surgeons operate guided by virtual images of internal organs projected on the patient's skin.

The National Rehabilitation Hospital (NRH) Rehabilitation Engineering Service, with Michael Rosen, Ph.D. as its director, has a professional staff of seven, and a support staff of two, and is recruiting new staff at both levels. There is ongoing collaboration with NRH physicians and psychologists, and with colleagues from the Biomedical Engineering and Psychology Departments at the Catholic University of America.

Like many groups around the country and abroad, investigators at NRH are looking into the potential benefits of VR for individuals with disabilities. The purpose is not to offer virtual experiences as a substitute for interaction with the real environment, but to provide evaluation and training that will support the individual's efforts to fulfill his or her own goals in the real world.

Early work at NRH produced a "Virtual Shopping Cart," successfully in an empathic experience for users; the goal is to approximate the challenges confronting the person with disability (see Figure 1). In this case the experience of visuospatial neglect is simulated for family members of the individual recovering from a stroke. Visuospatial neglect can be thought of as a failure to attend to stimuli appearing on the side opposite to the affected brain hemisphere, particularly when the stroke has damaged the right hemisphere. In practical terms, the patient may not notice someone standing on her left, or may fail to eat the food on the left side of his plate. The virtual experience has two modes of operation. In "non-disabled" mode, the VR participant steers the cart through shoppers and traffic while fully aware of the surroundings. Under the visual neglect condition, the participant fails to see what is on the left side, and steering becomes much less successful.

A current focus of VR work at NRH involves not only display, but also sensing of direction of gaze. An eye-tracking camera has been installed in the VR headset so that the direction of gaze of the right eye is sampled up to 60 times per second. This system has been used to examine stroke patients' attention to objects on the left side of space. A study now in progress uses the system to investigate face recognition by persons with autism. Participants are asked to look at three-dimensional, static images of faces and objects. They are then shown more images, and their task is to report whether they have previously seen each image, or not. The primary hypotheses are that individuals with autism will show greater impairment in face-recognition (relative to object-recognition, as compared with controls) and that their gaze patterns will differ from controls'. While only a few individuals have participated so far, preliminary evidence is consistent with these predictions. Typically, individuals' face recognition accuracy declines when the faces are presented upside down, since the configural information important to face recognition is lost when faces are inverted. Unlike controls, persons with autistic disorder are no worse at dealing with inverted faces than they are with faces in their usual, upright orientation. The implication is that they base their judgments on featural rather than configurational information.

Findings of anomalous gaze suggest that training in effective face-gaze may be a useful component of intervention for persons with autism. If

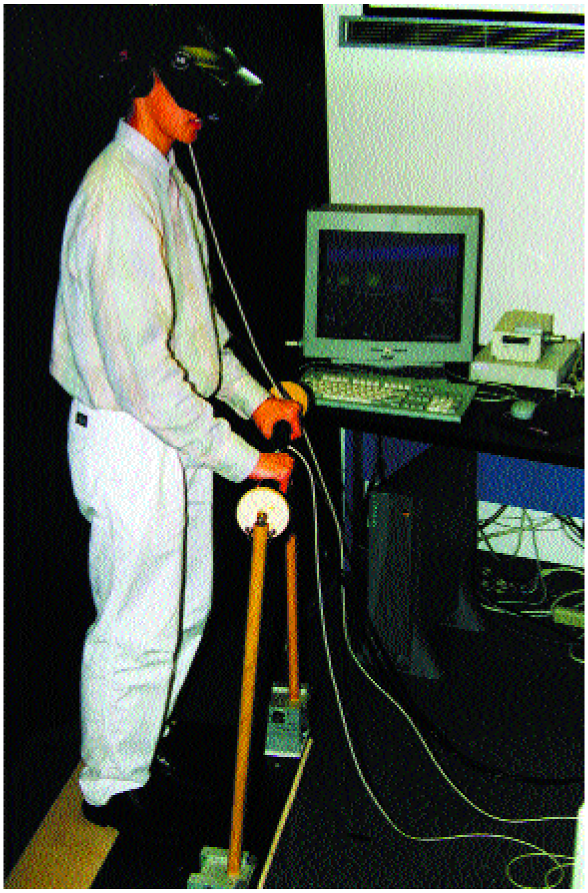

Figure 1. Operating the Virtual Shopping Cart to gain empathy with stroke patients.

the data continue to bear out our hypotheses, that is an avenue we will pursue.

Training in social skills is also of vital importance for individuals with autism. For many, social skills deficits represent the major barrier to employment. VR offers an exciting way to approach teaching and practicing these skills. Situations can be presented that could be dangerous if encountered in real life. One goal of training must be to reduce the likelihood of the sort of behavior that leads to victimization, or causes others to become fearful, call the police, or even resort to violence. A large number and variety of scenarios can be presented, and rewards can be built in, so that the individual is motivated to engage in the therapy often and at length. A therapist need be involved only in an executive role—reviewing data downloaded from the system to monitor progress and interest, and selecting new scenarios when warranted.

A project just beginning at NRH is the development of the "Virtual Mall." Using software developed for the training of emergency and military personnel who encounter culturally unfamiliar and threatening situations, the Virtual Mall will be populated with virtual human beings who will respond to the participant's direction and speed of movement, contact, and speech. The metaphor of the soldier deposited in alien territory is an appropriate one for the individual with autism trying to cope with the social world. The behavior of others is as inexplicable and unpredictable for persons with autism as the actions of members of an unfamiliar culture are to the young peacekeepers.

The long-term prospect, we hope, will be social skills experiences provided over the internet to individuals with autism, in their own homes, at times they prefer. Eventually it may be possible for individuals with autism to preview new situations, practice appropriate behavior for attending a concert, buying groceries, or rehearsing job interviews, so that they can take on the outside world with reduced anxiety and with a greater likelihood of connecting with others.■

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